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ABSTRACT

This report examines the theory that when people understand a text, they create a complex scenario (or model) within which the events described might plausibly occur. In order to study construction and revision of such models, five subjects were given difficult-to-understand texts, and were later asked to discuss the processing they went through to make sense of the text. The results indicated that skilled readers use a variety of strategies for revising and evaluating different models, finally converging on a model that best accounts for the events described in the text. Protocols are used to describe specific strategies used in constructing an initial model of the text, revising the model, and evaluating the model. The report concludes that pinpointing the strategies that skilled readers use for dealing with difficulties in understanding will help to specify the strategies which unskilled readers must learn. (AA)

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INFERENCE IN TEXT UNDERSTANDING

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INTRODUCTION

When people understand a text, they do not simply connect the events in the text into a sequential structure. Rather they seem to create a complex scenario or model within which the events described might plausibly occur (Bransford & Johnson, 1973). This model-based view suggests that we cannot characterize inference procedures solely in terms of finding connections between elements in a text. But it in turn raises a number of unanswered questions about how people understand texts. For example:

1. What precisely is meant by a model of the text?
2. How do people synthesize these models?
3. How do people revise their initial models?
4. Why do people select one model over another?

In order to study how people construct and revise models, we gave subjects five difficult-to-understand texts and recorded protocols of the processing they went through to make sense of the texts. The results indicated that skilled readers use a variety of strategies for revising and evaluating different models, finally converging on a model that best accounts for the events described in the text. These strategies concern the ways that skilled readers deal with the difficulties that arise in comprehension. By making these strategies explicit, we can possibly provide less skilled readers with strategies for what to do when they don't understand a text.

Text-Based vs. Model-Based Inference

Classically in cognitive psychology and artificial intelligence, inference is thought of as filling in the missing connections between the surface structure fragments of the text by recourse to context and knowledge about the world. This text-based view of inference stresses the notion that the inference process looks for meaningful relations between different propositions in the text. Such a view permeates semantic network theory (Quillian, 1969; Rumelhart, Lindsay & Norman, 1972), conceptual dependency theory (Schank, 1972; Rieger, 1975), demon-based approaches (Charniak, 1972) and cognitive psychology (Anderson & Bower, 1973; Frederiksen, 1975; Kintsch, 1974).

An alternative model-based view argues that a central purpose of inference is to synthesize an underlying model, which organizes and augments the surface structure fragments in the text. In this view, inference is controlled by a target structure that specifies the a priori constraints on the kind of model to be synthesized. This target structure acts as an organizational principle for guiding a set of inference procedures.

If this target is a non-generative structure, then this view is extremely similar to the view that the purpose of inference is to select and fill out a set of frames (Charniak, 1975; Minsky, 1975; Winograd, 1975) or scripts (Schank & Abelson, 1975; Lehnert, 1977) or schemas (Bobrow & Norman, 1977; Rumelhart & Ortony, 1977). If, however, the target is a generative structure, like a grammar, it can produce a potentially infinite number of possible models. In

the latter case, the control exercised by the target structure is more subtle, requiring the growing of the target structure hand in hand with filling in the variables of the model (Bobrow & Brown, 1975).

Methodology for studying model-based inference

We studied the four questions in the first section by reading five short, but difficult-to-understand passages to four different subjects. We recorded the subjects' protocols after they had heard the entire text. The subjects were asked to describe how they processed the text, whether they had any intermediate hypotheses along the way, whether they were satisfied or dissatisfied with any of these hypotheses, and why. Subjects could ask to have the text reread if they wanted. The texts ranged from a fragment of a mystery story to a recipe for an unspecified food. Analysis of these protocols suggests some initial answers to the questions listed above.

Two of the texts we used are given below. We will describe our theory of text understanding in terms of how two of the subjects dealt with these texts. At the same time we will try to point out other cases where the same phenomena occurred in other protocols. It will help the readers to think about and remember their own processing as they read these texts:

Window Text

He plunked down $5 at the window. She tried to give him $2.50, but he refused to take it. So when they got inside, she bought him a large bag of popcorn.

Boating Text

John and Bill were sailing on Mystic Pond and they saw a coffee can floating in the distance. Bill said, "Let's go over and pick it up." When they reached it, John picked it up and looking inside said, "Wow, there are rocks in the can." Bill said, "Oh, I guess somebody wanted the can to float there."

Because the passages were difficult to understand, subjects were able to give us valuable clues to their model-synthesis process. Equally revealing were the unsatisfactory hypotheses that people discarded along the way, and the reasons why they decided to do so. The theory described below is our interpretation of the processing revealed by these subjects' protocols.

A PROGRESSIVE-REFINEMENT THEORY OF TEXT UNDERSTANDING

Overview of the Theory

We will outline our theory briefly first. Then we will expand each of these ideas in more detail. The theory states that text understanding proceeds by progressive refinement from an initial model to more and more refined models of the text. The target structure guides the construction process, constraining the models to the class of well-formed, goal-subgoal structures that means-ends analysis (Newell & Simon, 1963) produces. The initial model is a partial model, constructed from schemas triggered by the beginning elements of the text. Successive models incorporate more and more elements from the text. The models are progressively refined by

trying to fill the unspecified variable slots in each model as it is constructed. As the questions associated with the unfilled slots in more refined models become more and more specific, the search for relevant information is constrained more and more. The overall process is one of constraint satisfaction (Fikes, 1970; Waltz, 1975).

The refinement process makes use of a variety of general-purpose problem solving strategies. These include rebinding a variable when its binding leads to a conflict, trying different variable bindings when there are a number of possible alternatives, questioning the bindings on other variables that lead either directly or indirectly to a conflict, questioning any default assumptions when there is a conflict, and focusing on another part of the problem when you aren't getting anywhere. People pursue this refinement process until it converges on a solution that satisfies a number of conditions for a plausible model.

The Target Structure

The theory states that people try to understand the actions and events in a text in terms of characters applying means-ends analysis (Newell & Simon, 1963) to solve the problems that occur in the text. Means-ends analysis operates as follows: If there is a method to reach a goal directly and its preconditions are met, then apply that method. If the preconditions for the method are not met, then generate a subgoal to satisfy these preconditions. When a subgoal is generated, apply means-ends analysis recursively to reach that subgoal. If there is no way to satisfy the preconditions for that

method, then look for another method that can be applied to reach that goal, etc. Means-ends analysis thus puts certain constraints on the permissible structures that interrelate events in the text. For example, a subgoal must be a means to satisfy the preconditions for a method applicable to a higher goal. Failures in trying to apply a method must lead to application of other possible methods for obtaining the same goal or a higher goal. But within these constraints there are still a potentially infinite set of plans or solutions to a problem depending on the particular subgoals and methods generated.

Story grammars (Mandler & Johnson, 1977; Rumelhart, 1975, 1977b) are an attempt to specify the class of well-formed target structures in the domain of stories. But the target structures for other domains pertinent to text understanding can also be characterized as goal-subgoal structures. For example, the recipe used in our study consists of a set of steps for mixing ingredients and then steps for cooking. Subjects attempted to understand the recipe by figuring out the overall goal of the recipe, from the set of subplans specified in the recipe. These target structures are a kind of tacit knowledge that guides people to make sense of texts in terms of goals and subgoals.

What is missing from story grammars, but is crucial to the way a target structure guides the construction of models is a notion of planning knowledge (Brown, Collins, & Harris, 1978). In the domain of stories this planning knowledge consists of knowledge about social goals and deltacts (i.e. acts to reduce differences between

present states and goal states), about specific methods for achieving particular deltacts, about the ordering on these methods, and about the preconditions and results of each method (Abelson 1975; Schank & Abelson, 1977). This planning knowledge places enormous constraints on the way people construe stories; for example, giving somebody money is a method for getting that person to give you possession of something, but it is not a method for conveying information to them. In order to construct a model of the text, the comprehender must identify events in the story with different methods, figure out the goals that those methods are being used to achieve, identify whether those methods succeed or fail, bind successes to satisfy preconditions for higher goals, and relate failures to alternative plans to achieve the same higher goals. In the next section we will try to indicate how this planning knowledge is invoked in constructing a model of the window text.

Constructing an initial model of the text.

We can best illustrate the process by which subjects construct a model in terms of the window text, because this text almost always leads people down a false path. The protocol below shows the kind of mistake subjects make initially in interpreting this text.

> When you said he plunked down $5 at the window, I thought he was at the racetrack, because I decided it was a betting window. The amount of money really didn't tell me anything. I didn't think the $5 was what you bet on a horse or anything like that, but somehow the window part

of it; I don't think of the movie theater as having a window, I think of it as a box office. And the only place I can think of as a window is a betting window. So I thought that was a racetrack.

So then when you said she, I thought that was the person behind the window. And when she tried to give him $2.50 back, I thought that was his change. When he said he wouldn't accept it, I started wondering. Because I can't imagine anyone not accepting his change from a bet at a horsetrack. If the next sentence had been something like he gave her $.50 because that had really been $3 instead of $2.50, then that whole hypothesis would have fit together. I prepared myself for that; I had that expectation that there was going to be some sort of exchange of how much the bet really was. I was trying to hang on to my original hypothesis which was that he was at a racetrack.

The second sentence was harder to integrate into that hypothesis, because it said that she tried to give him $2.50 back - it didn't say back, I guess. She tried to give him $2.50 but he refused. I was trying to integrate that into the racetrack hypothesis. And in order to do that, I had to believe that the $2.50 was his change and that he refused because it was the incorrect amount, but I was suspicious at that point, because that seemed a little strange; that didn't quite fit in.

Then when you said, when they got inside, I believe was the next sentence, I realized that I was wrong because there was no reason for him and the woman behind the window to be going anywhere together. I realized that the person he'd given the money to was not the same as "she" in the second sentence, and in fact they meant he and the "she" who had tried to give him the money, and suddenly I realized that she must have been his date, and it's hard to say if I really realized it at that point or at the point where you said, "so she bought a big bag of popcorn," or whatever the rest of it was. But then I had to reinterpret where the $2.50 had been coming from and it all made sense; it came from his date and she wanted to go dutch and he didn't, and so she bought the food when they got inside.

Here we see the phrase "he plunked $5 down at the window" very quickly triggers the idea of a racetrack bet. For other subjects, it triggered a bank window or a theater window. Thus many subjects apparently make a fast jump to a specific hypothesis that may or may not be correct (Rubin, 1975).

How does such a phrase converge on one of these hypotheses? What should be emphasized about this process is that the "racetrack-betting schema," "the theater-going schema," and "the bank-teller schema" all exist as prior knowledge structures for the subjects. (See Schank, et al. (1975) or Lehnert (1977) for descriptions of a restaurant-going schema, or Charniak (1975) for a

description of a grocery-store-going schema.) These schemas function as highly-constrained structures, which are competing to fill their slots most successfully. This is a top-down process. Simultaneously the words in the text trigger a number of potential inferences. For example, $5 suggests the notion of buying or giving; window suggests a house, office, car, bank, theater, or racetrack window. These inferences are the kind that text-based theories have been concerned with (see section on Text-Based vs. Model-Based Inference). This is a bottom-up process. The selection of a particular schema, such as the racetrack-betting schema, depends on the conjunction of these two processes (Adams & Collins, 1978; Rumelhart, 1977a; Rumelhart & Ortony, 1977).

In the protocol each new piece of data from the text was assimilated to the initial model in order to construct more refined models of the text. Thus the "she" in the second sentence was identified as the only other person necessary in the racetrack-betting schema (or the bank or theater-going schema), that is, the receiver of the money. When "she tried to give him $2.50," people understood this as "change" which can be a subschema in any of the three schemas people selected (though not so easily in the bank-teller schema). But the man's refusal of the $2.50 causes trouble for the notion of change; subjects try to explain the refusal as a result of wrong change, but this seems shaky to them because outright refusal is not the usual way to deal with wrong change. Such a model is in worse trouble when "they" get inside. It is possible for the person behind the window to go inside with the man but highly unlikely. Many subjects probably introduced a

third person at this point. But when she buys him popcorn, all the subjects abandoned this incorrect model and jumped to the notion of a date. Thus all the subjects drastically revised their initial models in order to accommodate them to the information in the text.

Figure 1 shows the top-level structure of the model the subject constructed while processing the first two phrases of the window text. In a more complete representation of the model each box in the diagram would be expanded into its underlying semantic components (Schank, 1972; Norman & Rumelhart, 1975) and all the variable bindings (which are represented by arrows) would be shown. The arrows coming out of any box represent the variable slots in the schema for that concept (Norman & Rumelhart, 1975). These slots must be specified in the conceptual representation of any schema, such as putting, buying, or betting. We have represented unbound variables as pending questions in circles and bound variables as concepts in boxes. As the model develops over time, pending questions turn into bound variables.

The figure attempts to show the progressive stages of understanding and how these stages encompass the goals and intentions of the characters. The first stage consists of a set of pending questions that arise from the man putting down $5, such as "Who was he?", "Why did he do it?", "Where was he?" Many of these questions are answered as the subject's understanding progresses. The second stage reflects the notion that the man is putting down money toward the goal of buying something for which the money is payment. The third stage reflects the full notion that the man's goal is betting on a horse at a racetrack. At this point the subject has constructed an initial model of the text.

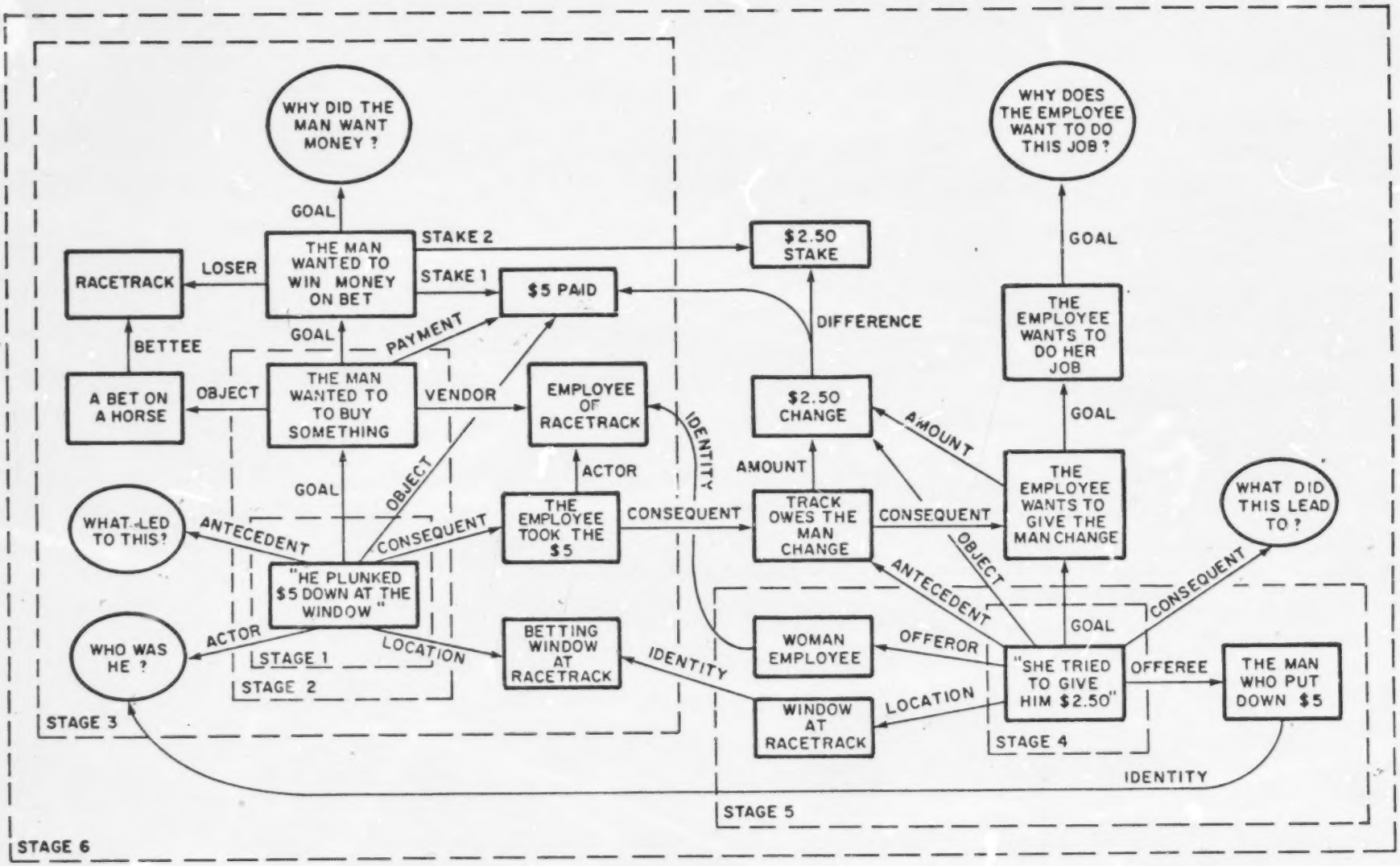

Figure 1. Stages in constructing a model

The next three stages show how new information is assimilated to the initial model. Stage 4 again consists of a set of pending questions about who tried to give whom $2.50, why they did it, and how this event is connected with the first event. Stage 5 proposes some tentative interrelations between the two events: "she" must be the racetrack employee who received the $5, and "him" must be the man who plunked down $5. In stage 6 the new information is fully assimilated, by constructing a goal for the employee of returning change to the man. This presupposes that the employee took the $5 and that the amount of the bet must have been $2.50. Thus the initial model is modified slightly to change the betting stake from $5 to $2.50. In general assimilation of new information is accomplished by filling in intervening structures based on the characters' goals and intentions, and making modifications to the original structures where necessary.

Figure 2 shows how a model is restructured when new information cannot be assimilated, as happened at the end of the window text. The new structure preserves a few of the original bindings: the plunking down $5 is still a "buying" event, the man who is offered $2.50 is still the man who plunked down $5, and there is still an employee who takes the $5. But most of the original bindings have been abandoned: a new character (i.e., the man's date) has been introduced, and it is she who offers the $2.50 in order to pay for her own ticket to the movie. The process of rebinding all the variables probably started with the introduction of this third character. Each new binding led to other new bindings until the

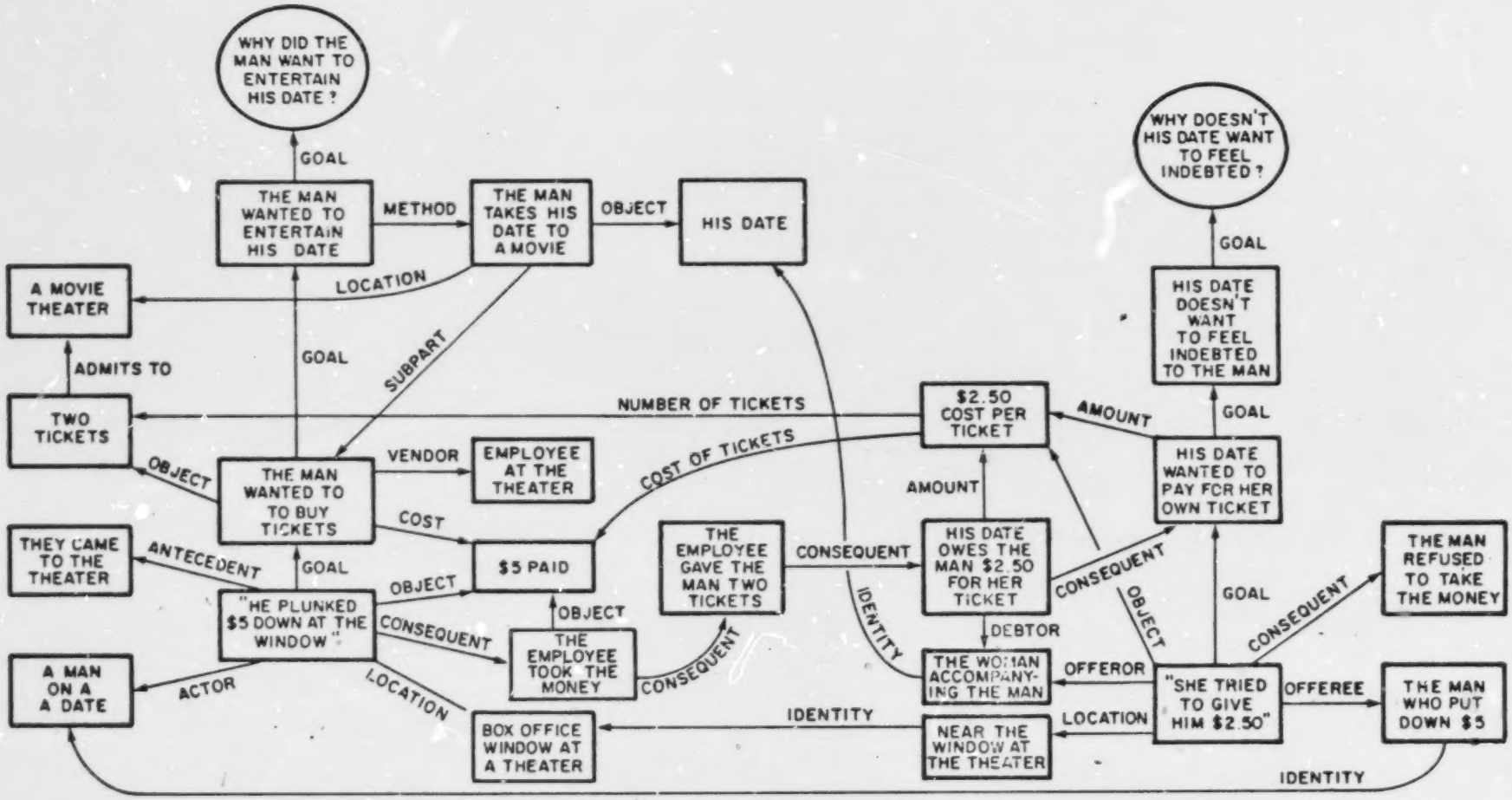

Figure 2. Restructured version of the partial model in Figure 1

model was completely restructured. However, the process occurred too quickly for the subject to describe; it is best seen in the next protocol where another subject was trying to make sense of the boating text.

The Questions Arising out of a Model

Any model the subject constructs raises a number of questions that the subject tries to answer. For example, in constructing a model for the window text, the subject considered the following questions: "Where were they?" "Why did the man plunk down $5?" "Who was the 'she' that tried to give him $2.50?" "Why did she try to give him $2.50?" "Why did he refuse the $2.50?" "Why did she go inside with him?" and "Why did she buy him popcorn?" Failure to answer any of the questions can lead to restructuring the model. Answering any of these questions leads to a more refined model, and puts additional constraints on the answers to the other questions.

These questions derive from the unfilled variable slots in the world knowledge schemas that are triggered by the understander's attempt to construct a coherent goal-subgoal structure. This is seen most clearly in a segment from a protocol on the boating text: "Well if it was an open can it might not float, if water got into it. Maybe if it was a closed can..." Here the subject is considering possible values for the "lid" variable in the "coffee can" schema. However, in most cases where the coffee can schema might be needed to understand a text, it would never lead to a question about the lid variable. Why does it in this text? The

reason is that the lid variable is crucial to finding a method for the goal of keeping the can afloat, which is a basic problem that arises out of the statement of the text. The subject eventually decided the can was closed. By fixing the variable in this way, she constrained the model in order to help her converge on a solution.

Sometimes questions arise out of the answers to other questions. For example, one of the subjects given the boating text was working on the question "What was the function of the rocks?" In doing so he considered the possibility that the rocks were lighter than water and that their function was displacement of water. This solution led in turn to two kinds of questions: "Are there lighter-than-water rocks?" and "What kept the rocks in the can?" The existence of pumice answers the first question, but in turn leads to questions such as "Would there be pumice around Mystic Pond?" The second question can be answered in terms of a lid, but this raises the question of "How does water get into the can for the rocks to displace?" These examples show how binding a new schema to a slot in order to answer one question can lead to other questions about how that schema interacts with the rest of the model. However, at some point the process must converge, because subjects usually do find a model that is satisfactory to them.

Constraint Satisfaction

The process by which people converge on a model that answers these questions involves constraint satisfaction (Bobrow & Brown, 1975; Fikes, 1970; Waltz, 1975). Constraint satisfaction occurs frequently in human problem solving. For example, consider

cryptarithmetic problems, such as Fikes (1970) or Newell and Simon (1972) analyzed. The problem is to figure out how to assign the digits (0-9) to letters so that the addition is correct:

DONALD

\+ GERALD

ROBERT

In this problem once the problem solver sees that E must be equal to 9 or 0, this constrains A to be either 4 or 5. To solve the problem, subjects make initial default assignments (such as E=9) and see if the constraints imposed by the assignments converge on a solution. Like means-ends analysis, constraint satisfaction is a pervasive part of cognitive processing.

Constraint satisfaction also arises in understanding scenes made up of toy blocks (Waltz, 1975). The problem is to identify the individual blocks making up the scene. In such scenes there are different patterns of edges that occur both at corners of blocks or where one block occludes another. The interpretation of one pattern is constrained by the interpretations of the adjacent patterns involving the same edges. In interpreting such scenes, the convergence time depends on the amount of ambiguity in the possible interpretations. As Winston (1977, p. 59) points out, if the process starts at the edge of a scene where there is less ambiguity, it converges much faster than if it starts in the middle of the scene. Similarly, if humans focus on the center of a scene, they find it much harder to identify the individual blocks, suggesting that human vision depends on a process like constraint satisfaction.

In understanding text, people try to answer the questions that arise out of the models they construct. When any question is answered, it constrains the solutions to other questions. Thus the bottom-up search for relevant information becomes more and more constrained as solutions to other questions are proposed. Sometimes the entire process converges too quickly for subjects to introspect about, as when the occurrence of "popcorn" caused a very fast restructuring of the answers to all the questions about the window text. Other times the process converges quite slowly as we will detail for the boating text. But we doubt that the slow convergence is a special case; rather we suspect it reveals the processing that occurs when disconfirming evidence as well as confirming evidence is encountered.

REVISING A MODEL

Problem Solving Strategies

In revising their model of a text, subjects bring to bear a variety of problem solving strategies. We can best describe these strategies in terms of their analogues in solving crossword puzzles. We have listed below some common strategies that people use to solve crossword puzzles. The column or row space where a word can be inserted in a puzzle is called a slot to emphasize its schema-theoretic correlate. In schema-theoretic terms the words inserted in the puzzle are the values assigned to variable slots.

1. If the word generated for a slot leads to a conflict, then generate a new word for that slot. (Rebinding)

2. If you cannot think of a word that satisfactorily fills a slot, then try to find another interpretation of the clue. (Question Default Interpretation)
3. If the word generated for a slot leads to a conflict with a crossing word, then question if that crossing word is correct. (Question Direct Conflict)
4. If the word generated for a slot leads to a conflict with a crossing word, then question the words that led to the selection of that crossing word. (Question Indirect Conflict)
5. If you cannot think of a word that satisfactorily fills a slot, then shift focus to find a crossing word to constrain the current slot. (Near Shift of Focus)
6. If you cannot think of a word that satisfactorily fills a slot, then shift focus to find a non-crossing word to constrain words crossing this word. (Distant Shift of Focus)
7. If there are a small set of possible words to fill a slot, try each one to see how they fit with possible crossing words. (Case Analysis)
8. If there are several possible words to fill a slot, tentatively try the most likely word. (Most Likely Case Assignment)

There are two aspects of these strategies we should explain. First, the two strategies we have referred to as "Indirect Conflict" and "Distant Shift of Focus" can be more or less indirect or distant. It depends on the number of steps between the new slot and the old slot in terms of crosswords. For example, a conflict or a shift can be one step removed to a slot that intersects a crossing word or two steps removed to a slot that intersects the one step

removed slot, etc. A shift of focus of several steps is usually tried only when a whole area is causing difficulty. Second, what we have called "Question Default Interpretation" is tied to a whole set of strategies for most skilled crossword puzzlers. For example, one such strategy is to view the clue as a verb if you've been viewing it as a noun. But these strategies are highly domain specific and don't concern us here. What is important for our purposes is how the eight strategies listed above appear to be domain independent.

A Subject's Protocol for the Boating Text

Most of these problem solving strategies can be seen in the following protocol for the boating text. Because of the length of the protocol, we have extracted only the most relevant segments:

1) Well immediately it doesn't make sense. I mean a can with rocks wouldn't float. I am going back. Mystic Pond, I don't think that could be anything other than a regular, unless it's a fairy tale in which anything could happen. I'm wondering if there is any other kind of coffee can it could be other than the round ones I'm thinking of. And I was wondering if there was any other kind of rocks there could be except the usual ones.
2) Well I thought about halfway through maybe they were ice sailing, but that wouldn't make sense that a can with rocks would float on ice, so I don't think they were ice sailing. It could be such salty water that a can with rocks would float in it. I think there is such a one out in Salt Lake City.

3) Somebody wanted it to float, so they put rocks in it. Well if it was an open can, it might not float if water got into it. Maybe if it was a closed can and there was air in it, it would float, but if it was closed why would they put rocks in it. I mean if it was closed and there was air in it, it doesn't seem like you would need rocks to keep it afloat. I'm baffled.

4) No, I wouldn't settle on anything I've said; nothing I've said really explains it.

5) Well the can was either opened and then somebody closed it using a plastic lid or some other kind of lid, in which case if they didn't open it, then I don't see how they could have gotten the rocks into it, so they must have opened it.

6) Maybe they put in a few rocks. Maybe that would make it drift, not drift as far, but I don't know whether that's true or not. Well if something's heavier, it won't move as fast with the same amount of force applied to it, so maybe they put a few rocks in.

7) Yeah, it says float <u>there</u>, not just float, so maybe they put a few rocks in to keep it relatively stable and then the rest was filled with air. I think that's what I would settle on.

8) Well, I am assuming that there's currents, oh it's a pond. OK, I'm assuming that there's currents or wind. Well, there must have been some wind because they went sailing so maybe if it was light like a leaf it would get blown

all over the place because an empty coffee can would be pretty light I would imagine. I think if they put a few rocks in, though, it might not sink and that would weigh it down a bit, so that it wouldn't get blown as far. That's what I would guess.

The questions that this subject was trying to answer were foremost "Why didn't the can sink?" and "What was the function of the rocks?" Other subjects addressed different questions, as we will show. The protocol shows abandonment of several answers to the first question, then a solution to it, (there were only a few rocks), and then a turning to the second question and a solution to it, (the rocks functioned as an anchor). The subject did not, in fact, arrive at the same solution as the one found by Bill in the story. Bill's solution was that the rocks functioned as ballast to keep the open can upright, and hence afloat. But the protocol does illustrate most of the different kinds of problem solving strategies that occur in the protocols collected.

Strategies in Revising a Model

The subjects were using the problem solving strategies listed earlier in order to figure out the meaning of the texts. We will give examples from the protocols of each of the strategies below:

Rebinding. The most common strategy seen in the protocols (e.g., in Segments 2, 5, and 8 above) involves rebinding the current slot. The strategy is simply: If a value that is bound to a variable slot leads to a conflict, then try another binding for that

variable. A clear case of the subject rebinding a previous solution to the question "Why didn't the can sink?" occurs in the second fragment. There she adopted a high-density-of-water solution by considering the water as ice. But this solution produced an immediate conflict: that the coffee can was said to be floating. To patch this high-density solution, she thought of another way (salt water) that water could be dense enough to hold up a rock-filled can. In the fifth segment the subject considers the possibility that the can had never been opened. This leads to a conflict with the fact that the can had rocks in it, so the subject resumes the assumption that the can had been opened. In the eighth segment, there was a patch of the anchor solution where the subject abandoned the notion that the can was anchored against currents, and instead decided it was anchored against winds. Rebinding involves keeping most of the model constructed up to the present point, and changing only the last variable bound.

Figures 3 and 4 depict two of the attempts at rebinding by the subject: Figure 3 shows the unsuccessful attempt in segment 2, and Figure 4 shows the successful attempt in segment 8. In each case the model constructed in attempting to answer a particular question had an unbound slot that needed to be filled to make the model plausible. (We have depicted the models here as a metaphorical image that may not be too different from the kind of model people actually have.) A first attempt at binding the slot failed on the basis of the evaluation strategies described below. In Figure 3 the

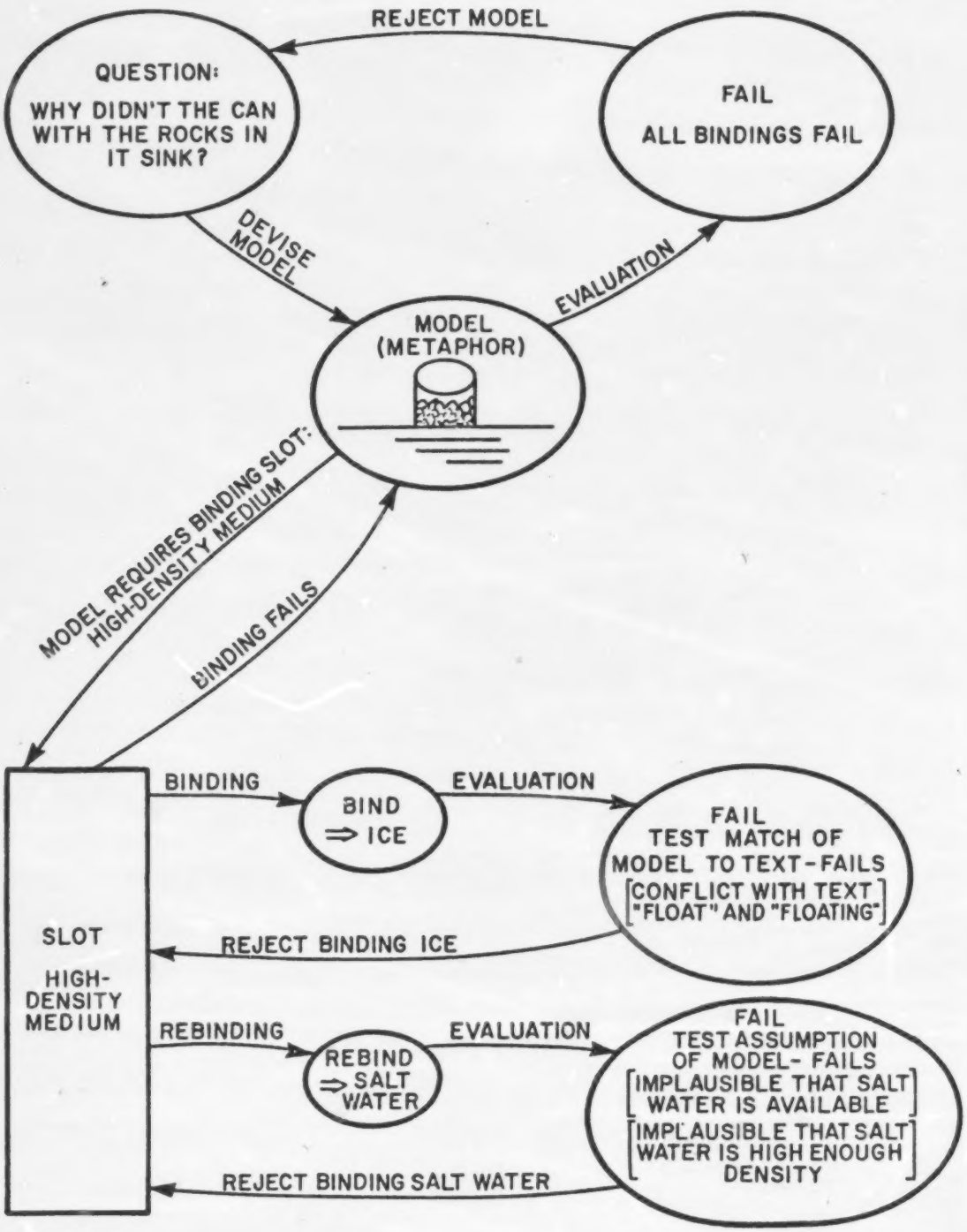

Figure 3. Rebinding the slot for a high-density medium (protocol segment 2)

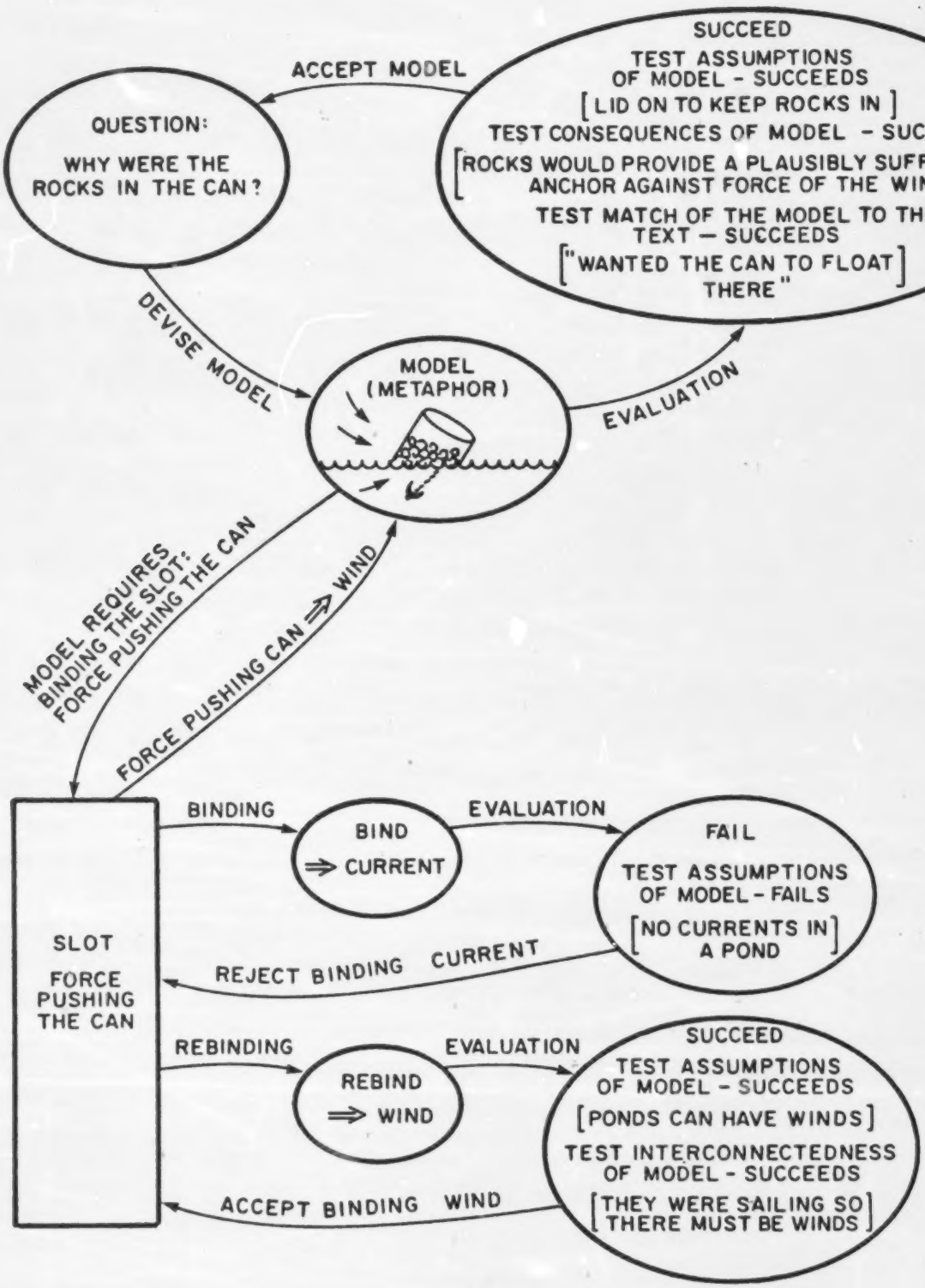
QUESTION:
WHY WERE THE ROCKS IN THE CAN?
ACCEPT MODEL
SUCCEED
TEST ASSUMPTIONS OF MODEL - SUCCEEDS
[LID ON TO KEEP ROCKS IN]
TEST CONSEQUENCES OF MODEL - SUCCEEDS
[ROCKS WOULD PROVIDE A PLAUSIBLY SUFFICIENT ANCHOR AGAINST FORCE OF THE WIND]
TEST MATCH OF THE MODEL TO THE TEXT — SUCCEEDS
["WANTED THE CAN TO FLOAT THERE"]
DEVISE MODEL
MODEL (METAPHOR)
EVALUATION
MODEL REQUIRES BINDING THE SLOT: FORCE PUSHING THE CAN
FORCE PUSHING CAN ⇒ WIND
SLOT
FORCE PUSHING THE CAN
BINDING
BIND ⇒ CURRENT
EVALUATION
FAIL
TEST ASSUMPTIONS OF MODEL - FAILS
[NO CURRENTS IN A POND]
REJECT BINDING CURRENT
REBINDING
REBIND ⇒ WIND
EVALUATION
SUCCEED
TEST ASSUMPTIONS OF MODEL - SUCCEEDS
[PONDS CAN HAVE WINDS]
TEST INTERCONNECTEDNESS OF MODEL - SUCCEEDS
[THEY WERE SAILING SO THERE MUST BE WINDS]
ACCEPT BINDING WIND

Figure 4. Rebinding the slot for the force pushing on the can (protocol segment 8)

second binding also failed leading to abandonment of that particular model. In Figure 4, however, the rebinding succeeded and the subject decided that the entire model was plausible.

Questioning a Default Interpretation. When subjects are not getting anywhere, they often begin to question their default assumptions. This can be seen most clearly in the first segment, where the subject considered changing her initial default assumptions that a) this is the real world, b) it is a standard coffee can, and c) these are normal rocks. Some subjects elaborate these possibilities by creating a fairy tale where the lake is only a little pond and the can rests on the bottom, or by assuming the rocks are lighter than water and their function is displacement of water. This is an important problem solving strategy, because assuming the wrong default values can often prevent subjects from finding the correct solution, as happened to the subjects who decided the coffee can was closed.

Questioning a Direct or Indirect Conflict. The strategy of questioning a direct conflict can best be seen in the earlier protocol on the window text. There the subject had bound the "she" in the text as the person who received the money behind the window. However, when "she" went inside with the man, this led the subject to question her earlier binding of "she" to the person behind the window. This questioning of previous bindings is rather prevalent in dialogues.

Sometimes the questioning of a particular binding may only occur through a chain of inferences that are needed to support a particular binding. For example, one subject had decided the coffee can was covered with an air-tight plastic lid. This binding was made when he initially heard in the text that the coffee can was floating in the distance. Later when he was considering the question about the function of the rocks, he considered the possibility that the rocks were lighter than water (e.g. pumice) and their function was to displace water. In order to displace water, water had to be able to get into the can without the rocks getting out. This led the subject indirectly to question the earlier lid binding: what he needed was a leaky lid. Thus through a whole chain of bindings the subject was led to question a binding made much earlier.

Near or Distant Shift of Focus. Subjects in the protocols sometimes move from a question they can't solve to a different question. Often the new question is closely related to the old question. For example, between segment 2 and segment 3 of the protocol shown for the boating text, the subject changed the question she was addressing from "Why didn't the can sink?" to "What was the function of the rocks?" Then during segment 3 she changed to the related question "Was the can open or closed?". Another subject, when he wasn't getting anywhere with the question about the function of the rocks, considered the more distantly related question "What was the intention of the people who put the rocks in the can?" By addressing a different question when in trouble, the subject frees himself of some of the assumptions he's made in

constructing his current model. It gives the subject a new perspective by allowing him to start binding variables in a different part of the structure (see paragraph on Constraint Satisfaction in Vision).

The reason this strategy works is that the answer to one question constrains the answers to other questions. For example, the subject's solution in the sixth fragment that the can floated because there were only a few rocks, apparently suggested the anchor solution to the function question. Another subject, when he heard the ballast solution, answered the question about the intention of the people who put rocks in the can as follows: they must have been kids who wanted the can to float, and to prevent it from floating on its side, they put rocks in. Addressing different questions in order to constrain other variables helps the subject converge on a solution from a different angle.

Case Analysis and Most Likely Case Assignment. Often subjects make tentative assignments as a deliberate strategy to constrain the possible solutions so that the process will converge. Case analysis is the systematic consideration of all alternatives possible cases. This is what the subject did in the third segment, where she considered whether the can was open or closed. Then in segment 5 she elaborated her model by making several likely case assignments: that the can was closed, that a plastic lid was used, and that it was empty except for the rocks. But these were tentative assignments of variables; they were chosen only because they were the most plausible values. Hypothetical reasoning on cases (i.e.,

choosing either the most likely case, or the case that might constrain the model the most) is a standard technique in constraint satisfaction. By pinning these variables down to their most likely values, the subject hoped to impose enough constraint so that the process would converge (see section on Constraint Satisfaction).

Figure 5 depicts the case analysis strategy used by the subject in segment 3. There the subject tried to bind the lid variable in order to constrain her model. The first binding failed but the second succeeded at the level of the particular slot it filled. However, the entire model failed, because it didn't answer the basic question about the function of the rocks. This illustrates how the evaluation strategies described below are applied at different levels in testing the plausibility of any model.

Evaluating the Model

The protocols showed that subjects evaluated a number of models while trying to make sense of the texts. There are a number of strategies they applied in order to evaluate the models, and these strategies are linked to the conditions they used to either accept or reject a model. The evaluation process is a complex one, but we think we can specify at least four different tests that subjects applied in evaluating the plausibility of the models they constructed. The evidence from all these tests appears to be weighed together in evaluating the plausibility of any model.

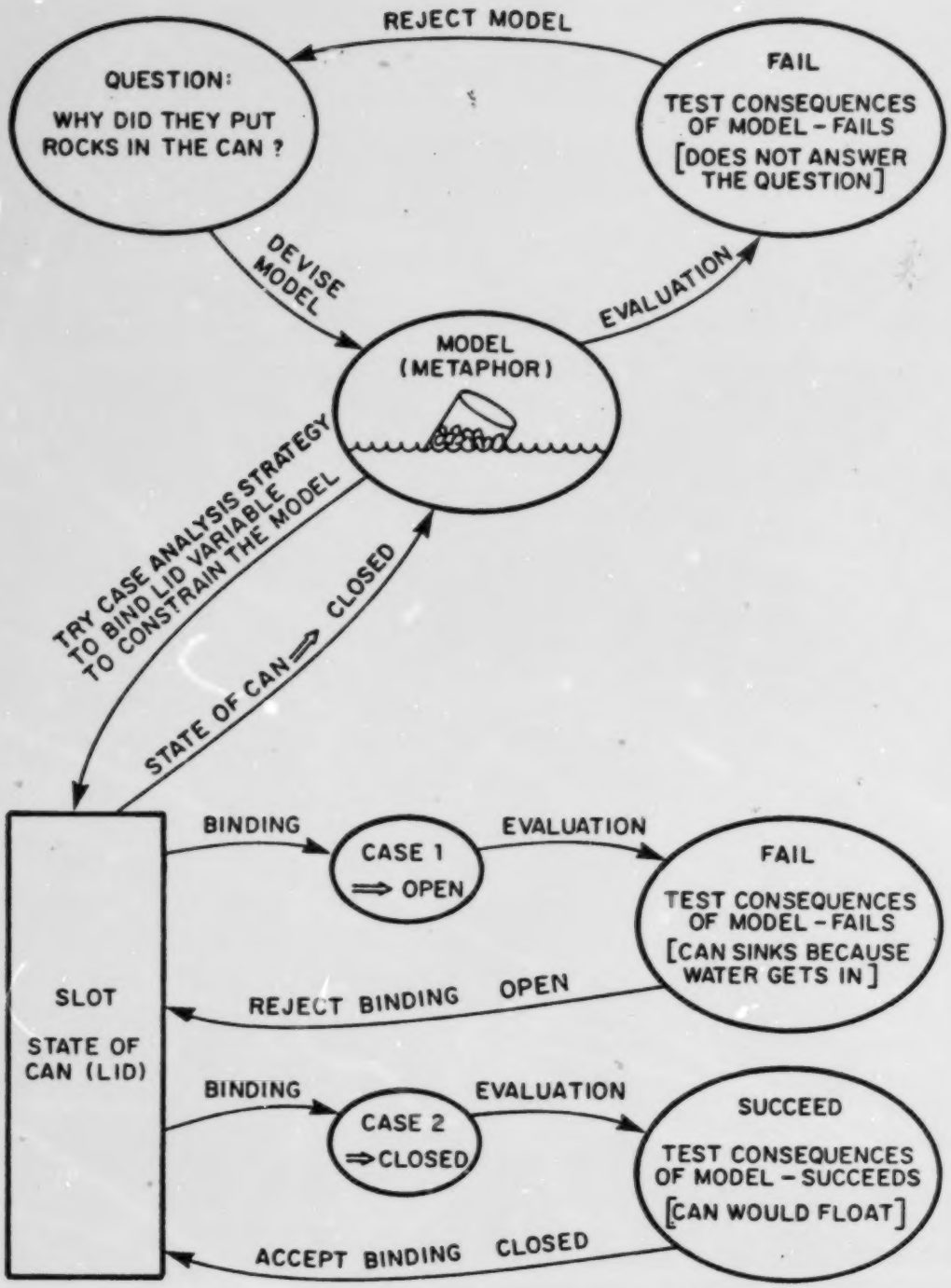

Figure 5. Case analysis for the lid variable (protocol segment 3)

1. The plausibility of the assumptions and consequences of the model. In constructing any model, it is necessary to fill a number of slots in the model with default values. Furthermore, the model has certain consequences that follow from it. There are a number of places in the protocols where subjects clearly are testing the plausibility of the model's default assumptions and consequences. For example, in the second segment of the protocol, the subject tried to test the likelihood that Mystic Pond might be salty. To do this she tried to think of cases of salt water lakes, and she came up with the Great Salt Lake in Utah. Apparently in part, because of the relative unavailability (Tversky & Kahneman, 1973) of salt water lakes among the lakes she knew, she decided it was fairly implausible that the Mystic Pond was salty. She may also have found it implausible that salt water would hold up a can filled with rocks. In the last segment she spent considerable effort elaborating the anchor model to see if she could think of some force (e.g. currents or winds) the rocks would anchor the can against. All of these are tests of parts of the model against the subject's world knowledge. They make use of the wide variety of strategies people have for evaluating plausibility (Collins, Warnock, Aiello, & Miller, 1975).

2. The completeness of the model. Models are evaluated in terms of how well the assumptions and consequences of the model answer all the different questions that arise. For example, the salt-water-lake notion answers the question "Why didn't the can sink?", but it doesn't answer the questions, "What was the function of the rocks?" and "What were the intentions of the people who put

the can in the lake?" Thus the salt-water model seems shaky because it doesn't answer important questions that arise with respect to the text.

3. The interconnectedness of the model. The assumptions or consequences of a model are weighed with respect to how they fit together with other aspects of the model. When particular assumptions are unsupported by other parts of the model, the whole model seems shakier. For example, when the subject was considering currents and winds as forces acting on the can, she rejected currents because they didn't fit with the fact that it was a pond. But she accepted winds because the people were sailing which requires winds. In her final model then, winds enter in two ways: to sail the boat and to provide a force to anchor the can against. Subjects appear to put more belief in the plausibility of the model if the different pieces tie together in more than one way.

4. The match of the model to the text. Very often subjects seem to weigh the model in terms of how well its assumptions or consequences match particular aspects of the text. For example, in the second segment the subject decided that "sailing" on the lake could be "ice sailing", but that if the can was held up by ice, it wouldn't really be "floating." Thus, we see a careful matching (Collins & Loftus, 1975; Smith, Shoben, & Rips, 1974) of the concepts implied by the model against surface aspects of the text.

In making judgments about the plausibility of a model, subjects weigh all these different factors against each other. Sometimes, each particular aspect of the model may be acceptable in and of

itself, but taken together the whole thing seems shaky. This may have been why the one subject rejected the salt-water model or another subject rejected the lighter-than-water-rocks (e.g. pumice) model. However, these four tests are not exhaustive; they merely encompass the major factors the subjects expressed concern about in the protocols.

In the subjects' evaluation of models there appears to be a parallel to the distinction in science between a model's ability to explain prior data and its ability to predict new data. For the most part in the protocols the subjects are evaluating prior data. But in the seventh segment there is a striking case where the subject's model led to a prediction that was confirmed by referring to the text (test 4 above). Her model implied that the function of the rocks was to keep the can stationary. Then looking at the text again, she found in Bill's remark a "there" which could be interpreted as meaning "in that one place." This confirmation of a prediction from the model seemed to give her much more confidence in her model. There is no way to tell for sure, but this suggests that making a successful prediction may act to increase confidence more than finding a successful account of prior data.

IMPLICATIONS FOR READING COMPREHENSION

In our schools we do not typically teach children what to do when they cannot comprehend a text. Furthermore, the strategies children have developed to deal with comprehension difficulties in conversation (e.g. ask a question or look puzzled) do not apply in reading (Rubin, 1978). At this point children need to develop a

whole new set of strategies for what to do when they don't understand. It is just such strategies that we see so ubiquitously in the protocols of the adults we studied.

One failure that occurred in the adult protocols is perhaps revealing of what may go wrong when a child cannot understand a text. One of the subjects, in dealing with the boating text, apparently failed to make much sense of it because she tried to answer the wrong questions about the text. First she dealt with the question "Who were John and Bill?" Because she quickly figured out who John and Bill were, she thought the problem for the reader in understanding the text was going to be to figure out their identities, just as in a mystery story. Bill's remark at the end then violated her expectations about the point of the story. This in turn led her to ask the question "Why didn't Bill explain what the rocks were doing in the can?" This too is a reasonable question about Bill's intentions, but it does not help find answers to the major questions posed by the text, i.e. "Why didn't the can sink" and "What was the function of the rocks." She did not ignore these questions altogether, but she did not focus on them enough to find a solution. Nor was she exceptional. Another subject, who focussed on the question "What was the intention of the people who put the rocks in the can," which seems from Bill's remark to be the correct question, also failed because the question leads down blind alleys. It brings up issues such as, "Who were the people who put rocks in the can?", "What were they trying to accomplish?" (e.g. catching lobsters or raindrops), "Were they playing some game, doing some job, or trying to confuse John and Bill?" These examples suggest

that one of the most critical skills may be to choose the right questions to focus one's problem solving skills upon. But the protocols do not tell us how people make these choices.

The theory outlined here provides a framework for studying specific questions about text understanding. For example: How do skilled readers formulate questions about a text? What strategies do they use to revise the models they construct to answer these questions? How do they evaluate those models? These questions address the strategies essential for dealing with difficult texts. By pinpointing the strategies that skilled readers use for dealing with difficulties in understanding, it should become clear what strategies unskilled readers must learn.

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